CHAPTER III

SECTION 3.0

FLUID ICE PROTECTION SYSTEMS

CHAPTER III—ICE PROTECTION METHODS

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SYMBOLS AND ABBREVIATIONS

Symbol	Description
AGARD	Advisory Group for Aerospace Research and Development
°C	Degrees Celsius
cm	Centimeter
cSt	Centi-Stokes (viscosity index)
°F	Degrees Fahrenheit
FAA	Federal Aviation Administration
FOD	Foreign Object Damage
FPD	Freezing Point Depressant
g	Gram
Hg	Chemical symbol for mercury
LWC	Liquid Water Content
m	Meter
MEG	Monoethylene Glycol
mg	Milligram
ml	Milliliter
mm	Millimeter
NASA	National Aeronautics and Space Administration
O.D.	Outside Diameter
SAE	Society of Automotive Engineers
WPAFB	Wright Patterson Air Force Base

III.3 FLUID ICE PROTECTION SYSTEMS.

III.3.1 OPERATING CONCEPTS AND COMPONENTS.

Fluid ice protection systems operate on the principle that the surface to be protected is coated with a fluid that acts as a freezing point depressant (FPD). When supercooled water droplets impinge on a surface, they combine with the FPD fluid to form a mixture with a freezing temperature below the temperature of the ambient air. The mixture then flows aft under the influence of the boundary layer and is either evaporated or shed from the trailing edge of the surface.

FPD fluid is distributed onto the surface leading edge to be protected by pumping it under pressure through porous material by channeling the FPD fluid along leading-edge grooves using centrifugal forces or by spraying the fluid onto a surface using an external spray bar. The use of a fluid freezing point depressant can provide anti-icing or deicing protection for almost any surface onto which the fluid can be distributed. The two primary means for accomplishing this are spray nozzles and porous skin panels.

Current systems normally use a glycol-based fluid. Descriptions of various FPD fluids and factors to be considered in fluid selection are presented in section III.3.2.4.

Fluid ice protection systems for fixed-wing aircraft were introduced in the mid-1930s by Kilfrost Ltd. and Dunlop Ltd. in Great Britain. Early systems used fabric wicks covered with wire gauze which was glued (or stitched, in the case of fabric-covered wings) to the airfoil leading edges. The development of armored leading edges with barrage balloon cable cutters during World War II created the need for a compatible ice protection system. Neither pneumatic boots nor the fluid systems then available were suitable, because their installation impeded the free sliding of the balloon cable along the leading edge.

In 1942, TKS (Aircraft Deicing) Ltd. was formed at the instigation of the British government to meet this need. This new company was formed by bringing together three companies with suitable specialist knowledge. “T” was Tecalemit Ltd., a company specializing in the manufacture of lubrication equipment, and in particular, metering pumps. “K” was Kilfrost Ltd., a chemical company specializing in deicing chemicals. “S” was Sheepbridge Stokes (now part of the GKN group), a company producing newly developed porous metals using powder metallurgy. TKS produced an ice protection system which used, as the fluid dispenser, tubes of 0.5-inch-square (1.3-cm) cross section which were recessed into the airfoil leading edges. The exposed face of these tubes was formed from porous powder metal through which the deicing fluid exuded. This so called “strip” system went into service towards the end of World War II and was extensively used on British and European aircraft. In about 1950, porous panels were introduced by TKS as a more efficient means of distributing FPD fluid onto the airfoil leading edges. Initially, the outer skin of these panels was formed from stainless steel powder and later from rolled and sintered wire cloth. Porous panels constructed from sintered wire cloth proved very successful and still form a significant proportion of production. Examples of panels manufactured from this material may be seen on all versions of the British Aerospace HS-125 aircraft, including the 125-800 version.

The main features of the porous panels remain unchanged from the designs of the 1950s, but recent designs utilize adhesive bonding and tend to extend beyond the minimum working region, often forming the complete leading edge. In such cases, the choice of material thicknesses and some construction features are usually influenced by structural strength requirements and bird strike and lightning strike considerations. The most recent development is the use of laser-drilled titanium for the porous leading edge. In comparison with sintered stainless steel mesh, this material offers a nearly 50 percent weight reduction, a greater resistance to impact damage, and a smoother surface finish. Examples of titanium panels may be found on the Cessna Citation SII (both civil and Navy versions) and the Beech Starship.

References 3-1 and 3-2 report the results of icing tunnel tests on various fluid ice protection installations that were conducted to improve the design database for this concept.

Reference 3-3 is an FAA Technical Note on FPD methods containing many helpful insights and certification considerations.

III.3.2 DESIGN GUIDANCE.

III.3.2.1 Anti-Icing.

When sufficient fluid is present so that at the point of maximum water mass collection, the freezing point of the water-fluid mixture is below the local air temperature, no ice will form and the system functions in an anti-icing mode. This is the normal mode of operation for a fluid system in light to moderate icing conditions. It is achieved by turning the system on prior to or immediately upon encountering icing conditions, then providing a continuous liquid supply in sufficient quantity to prevent ice formation.

III.3.2.2 Natural Deicing.

If icing conditions become too severe, there may be insufficient fluid flow to totally prevent formation of ice. When this occurs, ice will begin to form at the point of maximum accretion, usually at or near the aerodynamic stagnation point. If the fluid continues to be pumped onto the surface, the ice will not be able to bond firmly to the surface and the ice will grow until aerodynamic forces are sufficient to sweep it off the wet surface into the airstream. The process of periodic growth and shedding of ice, with the system in continuous operation, is referred to as the natural deicing mode of the system.

III.3.2.3 Deicing.

The deicing mode is a condition where ice is allowed to buildup before the FPD fluid flow is begun, thus allowing ice to accumulate and bond to the wing surface. When the fluid ice protection system is turned on, a flow is introduced between the ice and the surface to weaken the bond so that the ice will be shed by aerodynamic forces. However, there is evidence to suggest that, for some conditions, it may not be possible to deice a surface in this manner (reference 3-3). Fluid ice protection system testing should confirm satisfactory deicing over the full range of operating conditions that the aircraft is likely to encounter if certification for the deicing mode operations is desired.

Ice on windshields and ice accumulated aft of the active porous skin of a leading edge can be removed by spraying fluid, or allowing it to flow, onto the ice outer surface. With sufficient fluid, after a time interval, the surface ice will be both melted and loosened. Either of these two processes, in which the system is activated to remove established ice, is called the deicing mode.

III.3.2.4 Fluid Selection.

There are several chemicals which, when mixed with water, lower the water's freezing point. Glycol, alcohol, calcium chloride, nitric acid, and sodium chloride are among those that exhibit this characteristic (reference 3-3). The most commonly used chemicals for in-flight or ground deicing or anti-icing are glycol and alcohol. Glycol's freezing point is about 10°F (-12°C), but when mixed with an equal volume of water, the freezing point lowers to -10° to -40°F (-22° to -40°C), depending on the type of glycol. Fluid ice protection for an airfoil can be obtained by mixing glycol-based fluids and cloud water droplets on the airfoil leading edge.

Most fluids in the alcohol and glycol groups have freezing point depressant qualities that would make them suitable for ice protection purposes (see figure III 3-1); hence, their other properties are more important in choosing an appropriate fluid for a fluid ice protection system. See section III.3.10 for consideration of toxicity.

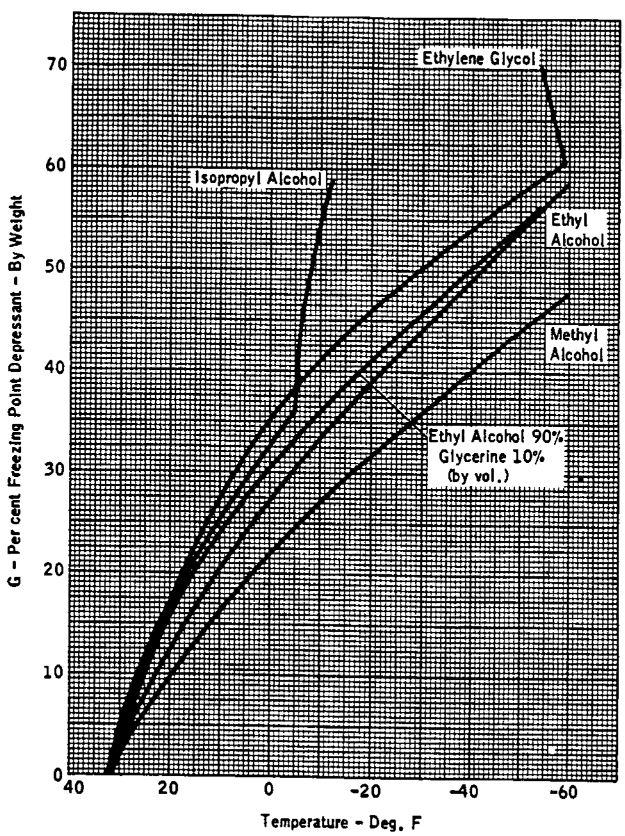


FIGURE III 3-1. FREEZING POINT PLOTS FOR AQUEOUS SOLUTIONS OF SEVERAL FREEZING POINT DEPRESSANT FLUIDS

For aircraft systems using a freezing point depressant fluid, service experience has shown that the most suitable fluid is a mixture consisting of about 80 percent monoethylene glycol and the balance distilled water, with possibly a small proportion of alcohol. Alcohols have been widely used in the past for windshield and propeller ice protection but they have the following disadvantages:

a. There is a high fire risk associated with alcohol.

b. Alcohol's relatively high volatility causes it to evaporate rapidly from the surface to be protected, reducing its effectiveness. The latent heat of vaporization tends to lower the surface temperature, aggravating the icing problem.

c. The viscosity of alcohols is too low.

d. In some cases (e.g., methanol) the toxicological hazard is unacceptable.

e. Alcohol may induce stress crazing of acrylic windshields.

The principal constituent of aircraft freezing point depressant fluids is monoethylene glycol (MEG). Physical properties of MEG are presented in table III 3-1 and figure III 3-2. MEG has suitable viscosity characteristics, although the temperature dependency is greater than ideal. It has a low volatility and presents a negligible fire hazard.

TABLE III 3-1. PHYSICAL PROPERTIES OF MONOETHYLENE GLYCOL

Formula	$HOCH_2CH_2OH$
Synonyms	1,2 ethane diol
	1,2 dihydroxy ethane
	MEG
Appearance/Odor	Clear, colorless, odorless liquid
Specific Gravity	1.115-1.116
Flash Point	241°F (116°C)
Boiling Range	383°-390°F (195°-199°C)
Freezing Temperature	See figure III 3-2
Auto-Ignition Temperature	743°F (413°C)
Explosive Limits in Air	Upper: 28% by volume
	Lower: 3.2% by volume
	Vapor Pressure 0.05 mm Hg @ 20°C
Viscosity	18.8 cSt @ 20°C
Miscibility With Water	Completely miscible

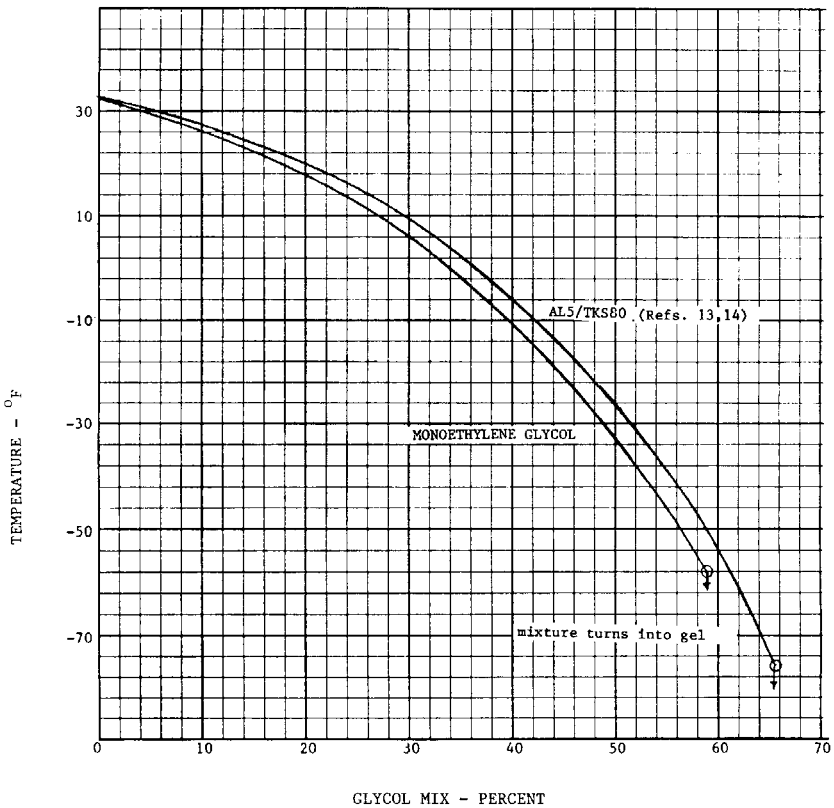


FIGURE III 3-2. FREEZING POINT DEPRESSANT FREEZE POINT INCREASE DUE TO DILUTION

The two most common fluids used in fluid ice protection systems today are TKS 80 and DTD 406B (also known as AL-5). Their characteristics are presented in tables III 3-2 and III 3-3 and in figures III 3-2 and III 3-3. At present, AL-5 is the more readily available fluid in the United States.

TABLE III 3-2. PHYSICAL PROPERTIES OF TKS 80

Composition, % Volume	80% monoethylene glycol
	20% distilled or deionized water
Appearance/Odor	Clear, colorless, odorless liquid
Specific Gravity	0.099-1.103 8 68°F (20°C)
Conductivity	4 micromho/cm
Viscosity	9.3 cSt @ 68°F (20°C) See fig. 3-3
Flash Point	None
Vapor Pressure	7.87 mm Hg 8 68°F (20°C)
Boiling Point	253°F (123°C)
Freezing Point	See figure III 3-2

TABLE III 3-3. PHYSICAL PROPERTIES OF DTD 406B (AL-5)

Composition, % Volume	85% monoethylene glycol
	10% distilled or deionized water
	5% ethyl or isopropyl alcohol
Appearance/Odor	Clear, colorless, odorless liquid
Specific Gravity	1.082-1.087 @ 20°C
Conductivity	5 micromho/cm
Viscosity	12.0 cSt @ 20°C (see figure III 3-3)
Flash Point	129°F (54°C)
Vapor Pressure	7.38 mm Hg (20°C)
Freezing Point	See figure III 3-2

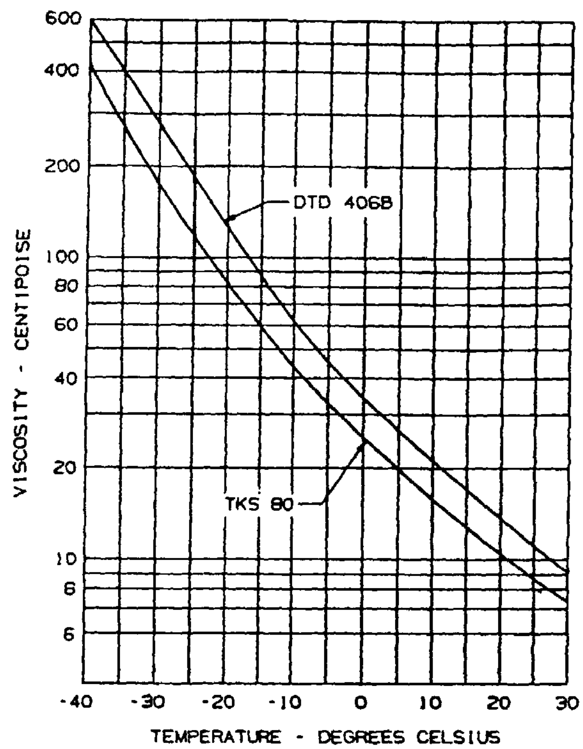


FIGURE III 3-3. VISCOSITY CHARACTERISTICS OF TKS 80 AND DTD 406B (AL-5)

The difference in viscosity between the two fluids makes it possible to extend the usable temperatures at either end of the range, depending on which fluid is chosen. There is virtually no difference in the freezing point of the two liquids in aqueous solution.

Many other fluid combinations may perform satisfactorily in a liquid ice protection system and better FPD fluids may be developed in the future. An ideal fluid will have a very low freezing temperature to minimize the flow rate required, and will have low viscosity sensitivity to temperature changes to reduce the range of operating pressures in the system.

III.3.2.5 Fluid Supply System.

A FPD fluid is stored in a tank installed at a convenient aircraft location. The location should provide easy access for tank refilling and for strainer replacement. The storage tank must be totally corrosion free. Suitable tank materials that have been used include anodized aluminum, stainless steel, plastic, and fiberglass.

In operation, the fluid passes through a strainer to a pump which meters the system's total fluid flow requirements. A filter should be installed downstream of the pump to protect system components against blockage by contamination from solid particles. The strainer between storage tank and pump should be nominally 20 microns. The filter, which is nominally 0.8 micron, causes a pressure drop that necessitates its location downstream of the pump.

Nylon is normally used for plumbing to distribute the fluid to the various system components. Pipe sizes generally range from 0.1875 inch outside diameter (O.D.) (0.5 cm) to 0.5 inch O.D. (1.27 cm), depending on the location and flow rate required. Special metal compression fittings should be used to ensure plumbing connection reliability.

The metering pump is usually driven by a direct current electric motor. This pump must produce a nearly constant flow rate nearly independent of back pressure. Two preset flow rates are normally provided. The higher flow rate can be used (1) for a preset period (e.g., 1 or 2 minutes) when the system is initially activated to establish flow and to remove existing ice; (2) to remove significant amounts of ice that have accumulated due to failure to activate system promptly; and (3) to provide anti-icing or natural deicing protection during abnormally severe icing conditions. The normal flow rate is designed to provide anti-icing protection during maximum continuous icing conditions. Manual flow rate selection should be available to the flight crew.

The filtered fluid is supplied to proportioning units in the surface being protected by the system. The proportioning units are essentially manifolds that contain calibrated capillary tubes, one for each outlet, which divide the total flow into the requirements of each porous panel on the leading-edge surface. Each proportioning unit outlet also houses a nonreturn valve to prevent porous panel drainage when the system is not in use.

Porous panels are constructed typically of sintered stainless steel mesh or laser-drilled titanium for the outer skin, a stainless steel or titanium backplate to form a reservoir, and a porous plastic liner to provide uniform control of panel porosity and sufficient resistance to fluid flow to maintain adequate reservoir pressure. If the reservoir pressure is not considerably higher than the air stagnation pressure, the flow rate will be attenuated at the stagnation point where the water droplet impingement is highest. A typical panel cross section is shown in figures III 3-4 and III 3-5.

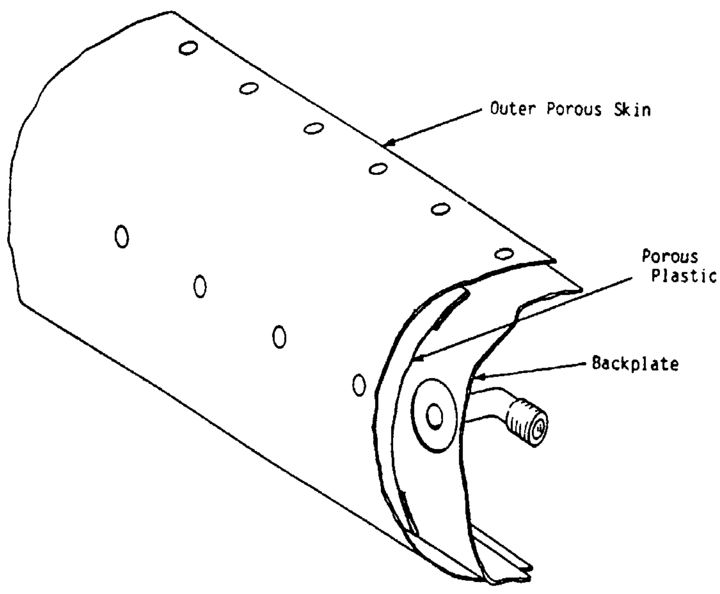


FIGURE III 3-4. CONTRUCTION OF A TYPICAL POROUS PANEL

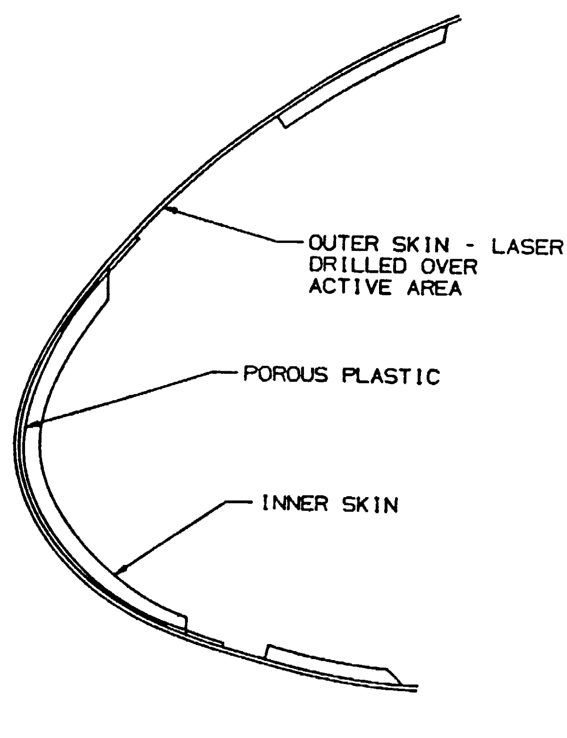


FIGURE III 3-5. CROSS SECTION OF A TYPICAL POROUS PANEL

The stainless steel porous skin consists of two or three layers (depending on strength requirements) of wire cloth that are rolled, sintered, and then finish-rolled to thickness. The layers are oriented 90 degrees with respect to each adjacent layer.

Using titanium instead of stainless steel provides a 50 percent reduction in panel weight, greater resistance to impact damage (including bird strikes), and improved surface finish. Further research is expected to produce other candidate materials and construction techniques for porous leading-edge panels.

III.3.3 USAGES AND SPECIAL REQUIREMENTS.

III.3.3.1 Airfoils and Leading-Edge Devices.

Panel installation on surface leading edges and other surfaces for which ice protection is required should cover the proportion of the span where ice protection is needed. The porous panel is positioned so that the stagnation point is well within the extent of an active portion of the panel over the entire range of angle of attack for which continuous protection is desired. The stagnation point travel is normally determined through wind tunnel tests or flight tests with the use of small tufts, wing pressure surveys, or by analysis. The panel active portion should extend 1 to 2 cm behind the extreme locations of the stagnation point to provide FPD fluid to mix with water impinging both above and below the stagnation region at all times, as illustrated in figure III 3-6. Porous panels may be designed to be part of an integral leading-edge structure (figures III 3-7a to III 3-7c (schemes A through E)) or may be added to an existing wing leading edge as shown in figure III 3-7c (scheme F).

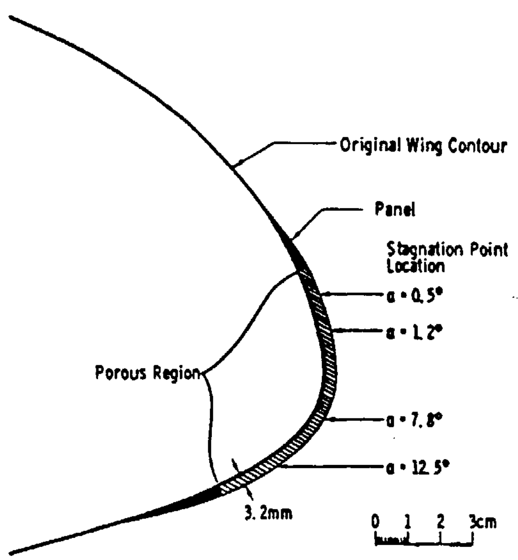
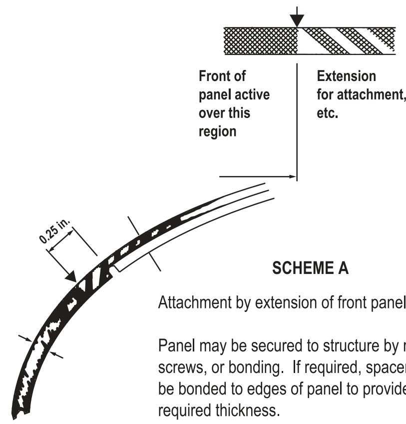


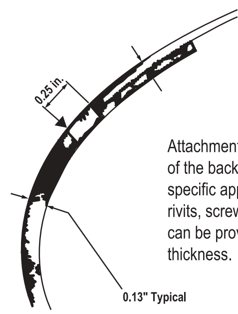
FIGURE III 3-6. TYPICAL PANEL INSTALLATION ILLUSTRATING ACTIVE REGION AND STAGNATION POINT TRAVEL



SCHEME A

Attachment by extension of front panel skin.

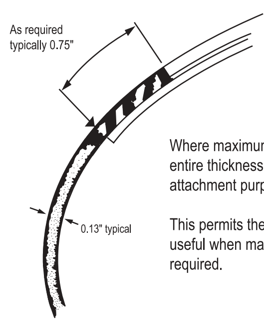
Panel may be secured to structure by rivits, screws, or bonding. If required, spacers can be bonded to edges of panel to provide any required thickness.



SCHEME B

Attachment by extension of backplate. The material of the backplate varies with the requirements of specific applications. The panel may be secured by rivits, screws, or adhesive bonding and dimension "t" can be provided as required to match the mating skin thickness.

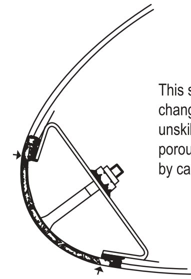
FIGURE III 3-7a. TYPICAL METHODS OF ATTACHING POROUS PANELS TO AIRCRAFT STRUCTURE (SCHEMES A AND B)



SCHEME C

Where maximum structural strength is required, the entire thickness of the panel can be extended for attachment purposes.

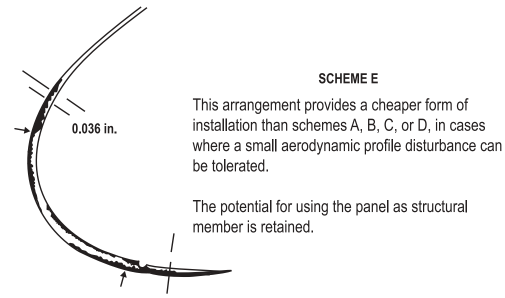
This permits the use of larger fasteners, and is useful when maximum resistance to bird strikes is required.



SCHEME D

This scheme is intended to provide total interchangeability with maximum ease of fitting by unskilled operators. Build tolerances of both porous panel and aircraft structure are eliminated by casting an accurate seating to all mating faces.

FIGURE III 3-7b. TYPICAL METHODS OF ATTACHING POROUS PANELS TO AIRCRAFT STRUCTURE (SCHEMES C AND D)



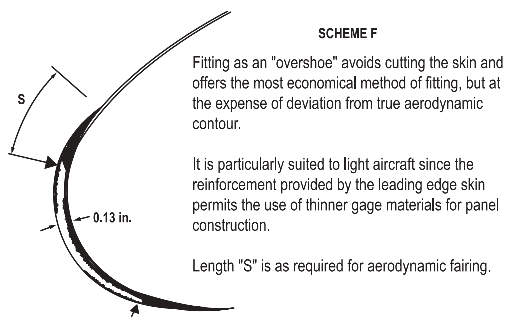


FIGURE III 3-7c. TYPICAL METHODS OF ATTACHING POROUS PANELS TO AIRCRAFT STRUCTURE (SCHEMES E AND F)

III.3.3.2 Windshields.

The spray nozzle distribution method is used primarily for windshield deicing. For this application a tube is installed at the base of the windshield behind a strip of material that deflects the airflow over the tube. Small holes are drilled in the tube at intervals of a few centimeters. The holes are located such that, when fluid is pumped into the tube, the holes direct a spray onto the windshield in the same manner as a conventional automobile windshield washing system. A separate pump is normally supplied for this application. The pilot actuates the system manually for a 5- to 10-second interval when it is necessary to clear the windshield. Several such bursts may be required to completely clear the window. Continuous anti-icing of a window could require excessive amounts of fluid and is not usually necessary.

III.3.3.3 Engine Inlet Lips and Components.

Porous panels may be manufactured in almost any shape permitting liquid injection anti-icing to be used on engine inlet leading edges. As on other surfaces, the panel active portion for inlet lips must cover the entire range of stagnation point travel, with 1 to 2 cm extra, depending on the inlet size. For turbofan engines, the fluid is normally swept aft on the inlet inside surface into the fan duct with no fluid entering the engine core. For pure jet engines, one should make sure that internal engine components and bleed ports are compatible with the glycol-based fluid and that contamination of bleed air for cabin pressurization is avoided.

To avoid ice ingestion damage, the fluid flow rate must be sufficient to achieve anti-icing protection or ensure that any ice shed is smaller in size than that permitted for ingestion, according to the engine manufacturer. This is also true for leading-edge segments of a wing that may be located ahead of an engine inlet.

III.3.3.4 Turbofan Components.

Fluid injection systems have not been used for internal turbofan engine components.

III.3.3.5 Propellers, Spinners, and Nose Cones.

Liquid ice protection of propellers can be achieved by distributing FPD fluid onto the leading edge of the propeller blades. This is accomplished by feeding the same fluid used on wing surfaces into a propeller slinger ring. The slinger ring retains the fluid by centrifugal force, allowing it to flow through a smaller feeder tube which deposits the fluid on the leading edge at the root of each blade. A rubber boot channels the fluid out along the blade leading edge to a point where centrifugal forces are sufficient to keep the blades free of ice.

III.3.3.6 Helicopter Rotors and Hubs.

The problem of rotorcraft ice protection is primarily related to the lifting rotor. The tail rotor can be protected using methods applied to conventional propellers while other surfaces can be protected in the same manner as a fixed-wing aircraft.

An experimental investigation of a liquid ice protection system on a helicopter rotor was conducted in 1961-62 (references 3-4, 3-5, and 3-6). The system used a slinger ring to transfer the fluid from a fixed nozzle to the rotating blades. Flexible hoses were used to supply fluid from the slinger ring to the rotor blades. The main rotor blades were production blades modified to include a fluid distribution system consisting of grooves milled into the forward and aft surfaces of the blade nose block and holes drilled into the stainless steel leading edge. The anti-icing liquid was channeled down the aft grooves, then forward to the two leading-edge grooves where it escaped through the holes in the leading edge and flowed over the blade surface. Tests in natural and man-made icing showed that adequate ice protection for the rotor could be achieved with such a system. Nevertheless, no further development was conducted on the system.

There are no helicopters in the U.S. that currently use a liquid ice protection system. However, a research project is now underway to develop a system using porous metal leading edges and a distribution system that minimizes the effect of centrifugal pressure gradients along the rotor span. It is believed that such a system can be feasible, effective, and practicable.

III.3.3.7 Miscellaneous Intakes and Vents.

The fluid injection method has been used to provide anti-icing protection of a large foreign object damage (FOD) deflector in front of the engine of the Westland Sea King helicopter. The FOD deflector tended to collect ice which could be ingested by the engine when shed. To prevent this, several flat porous panels were installed flush to the surface of the FOD deflector in chevron patterns. These were sufficient to provide full anti-icing of the deflector during normal flight operations.

III.3.4 FLUID AND WEIGHT REQUIREMENTS.

System weight is highly dependent on th`e FPD fluid reserve requirements. Fluid systems are unique in comparison with most other ice protection systems in that there is a finite endurance, depending on the quantity of fluid aboard. Requiring sufficient fluid to operate the system for the maximum endurance capability has been considered an unreasonable requirement (reference 3-3). Fluid requirements should be based on the airplane's operational environment and the icing envelope extent prescribed in Appendix C of FAR 25. Different minimum values of fluid duration may apply for airframe and engine. Some of the factors to be considered in specifying fluid minimums are as follows.

Jet aircraft generally fly above the icing environment for the majority of their flights, being exposed to icing conditions only during climb, descent, holding, approach, and landing operations. Since holding times at busy airports sometimes exceed 45 minutes, the FAA has required jet aircraft ice protection with accretions on the unprotected surfaces to be safe for operation at 0.5 g/m^3 LWC for continuous icing for 45 minutes.

Aircraft operating at lower altitudes, such as reciprocating engine and some turbopropeller-powered airplanes and helicopters, can be exposed to icing over a major portion of their flight profile. The system endurance should be consistent with this operating environment.

For gas turbine-powered airplanes with maximum operating altitudes above 30,000 feet (reference 3-3), fluid requirements, with continuous maximum fluid flow, are 90 minutes or 15 percent of the maximum endurance of the airplane, whichever is greater.

For reciprocating engine and turbopropeller-powered airplanes with maximum operating altitudes below 30,000 feet, continuous maximum flow of FPD fluid should be provided for 150 minutes or 20 percent of the maximum airplane endurance, whichever is greater.

In either case, a fluid quantity indicator and a low fluid level condition (for approximately 15 minutes remaining) should be installed in the cockpit visible to the crew.

Tables III 6-1 through III 6-10 in section III.6.0 provide estimated weights for fluid ice protection systems for various types of aircraft in comparison to other ice protection systems.

III.3.5 ACTUATION.

A fluid ice protection system can be actuated either manually or automatically. The primary control with automatic actuation is an ice detector to activate the pump whenever icing conditions are sensed. It is also possible to provide automatic timing and sequencing controllers to run the pump at high speed for an interval and then at normal speed. If an ice detector senses icing severity, it could conceivably regulate the speed of the pump to provide optimum fluid flow rate.

For visual ice detection, a location or object must be selected that ices before any other part of the airplane and is easily observable by the pilot both day and night.

Other automatic features available in fluid systems include the integration of pressure sensing switches with a programmed microprocessor controller. The controller automatically senses each failure then activates pumps and solenoid valves as appropriate to maintain system operation using redundant design features.

III.3.6 OPERATIONAL USE.

If icing conditions are anticipated in flight, the system should be activated during the preflight inspection to insure that fluid is being delivered to the surface of each panel, slinger ring, and/or windshield. This also serves to prime the system.

In flight, the system should be activated immediately prior to or upon entering icing conditions. This may be accomplished with the use of an ice detector as discussed earlier. Provisions should be made for the pilot to manually increase the flow rate (approximately double) to help protect against unusually severe icing conditions or to quickly remove any significant amount of ice that may have accumulated due to the failure to activate the system in a timely manner.

A gauge should be provided to monitor fluid level in the tank, perhaps combined with a low-level warning light. Handbook data can be used to translate fluid level to ice protection duration for different selectable flow rates. If pressure sensing switches are installed anywhere in the system (see section III.3.7), the panel should display the status of each switch to alert the pilot to any problem or failure.

III.3.7 MAINTENANCE, INSPECTION, AND RELIABILITY.

Maintenance of a fluid system is relatively simple and straightforward. All hardware components are designed to last the life of the airframe. Filters are normally replaced at regular intervals of 1000 flight hours or annually, whichever is shorter.

Porous panels are usually designed in 4- to 6-foot (1.2- to 1.8-m) lengths. Thus, if a panel becomes damaged for any reason, the replacement cost is minimized. Special attention is required in caring for the panels. They may be cleaned with only water and a mild soap or detergent. Oil-based deposits may be removed with alcohol or aviation fuel. Cleaning fluids or solvents can cause irreparable damage to internal panel components. Likewise any paint, wax, or polishing agents applied to the leading edge may plug up the porous panels, rendering them ineffective.

The clogging of holes in the porous leading edge by dust or insects has been a concern. However, flight tests at NASA Langley Research Center (reference 3-7) indicate that FPD systems may provide a means of removing the insect contaminant using very small fluid flow rates. The glycol-based fluid softens and removes the debris when the system is activated, similar to the process of backflushing a filter.

Other maintenance requirements involve periodic checking of all components for proper operation or leaks and making appropriate replacement of any defective components. If blockage occurs due to solids in the pipeline or proportioning units, the affected portion of the system must be thoroughly flushed with clean water. To prevent the accumulation of any water, foreign material, or air in any portion of the system, some fluid should always be in the reservoir and the system should be primed at regular intervals.

Fluid systems tend to be quite reliable because the pump is the only moving component. A high-quality pump is recommended to minimize the chance of failure. To assure system operation in the event of pump failure, systems may be designed with dual pumps. The two pumps may normally operate continuously with one pump at double normal speed, supplying the entire system in the event of a failure, or one pump may operate only in a standby mode.

Pressure switches can be provided at various points to monitor system operation and provide a failure indication if the operating pressures are outside normal limits. Duplication of critical items can be provided to meet various failure cases.

Figure III 3-8 shows a simple basic system with no redundant components and only one pressure switch. Figure III 3-9 shows a complex system with fully redundant pumps and supply lines to the proportioning units and numerous pressure switches to monitor system performance. Figure III 3-10 depicts a helicopter fluid ice protection system.

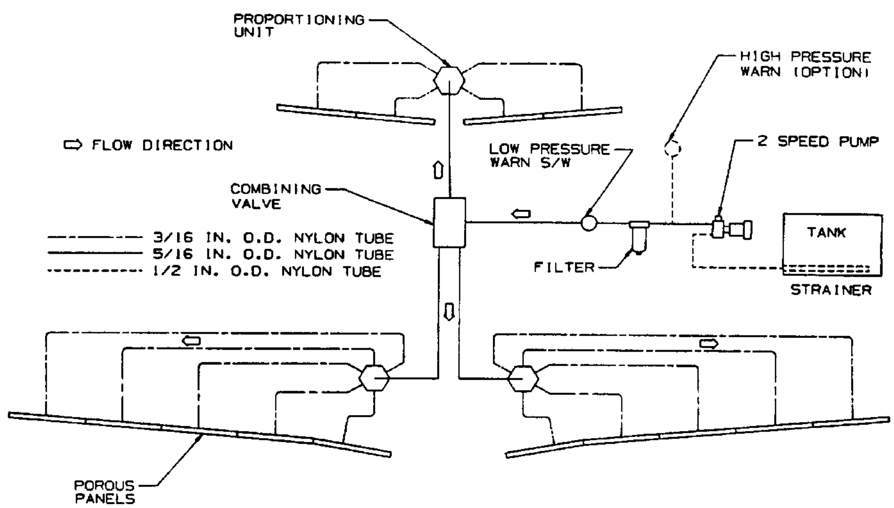


FIGURE III 3-8. SCHEMATIC OF A SIMPLE FLUID ICE PROTECTION SYSTEM

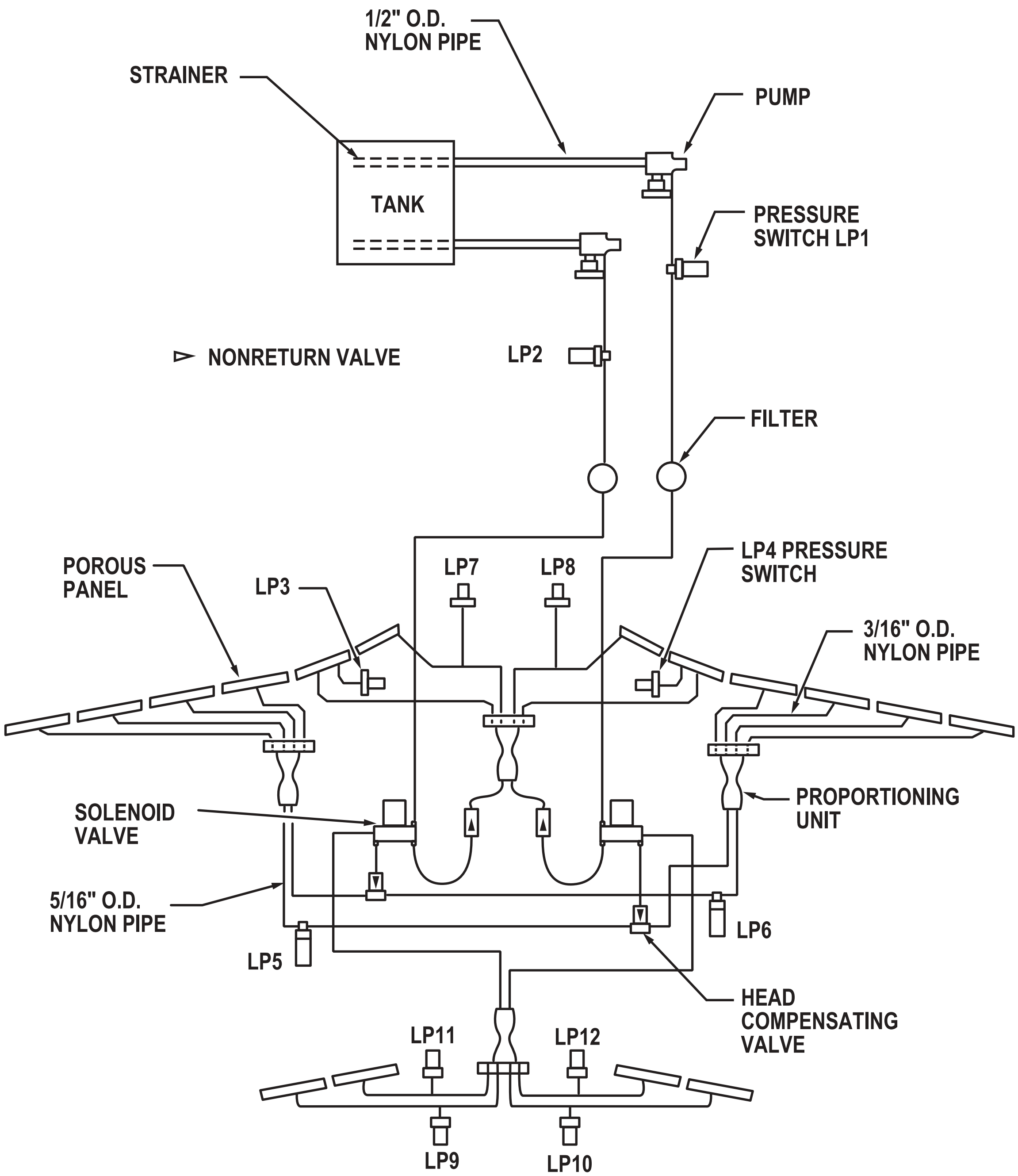


FIGURE III 3-9. SCHEMATIC OF FLUID ICE PROTECTION SYSTEM WITH FULLY REDUNDANT EQUIPMENT

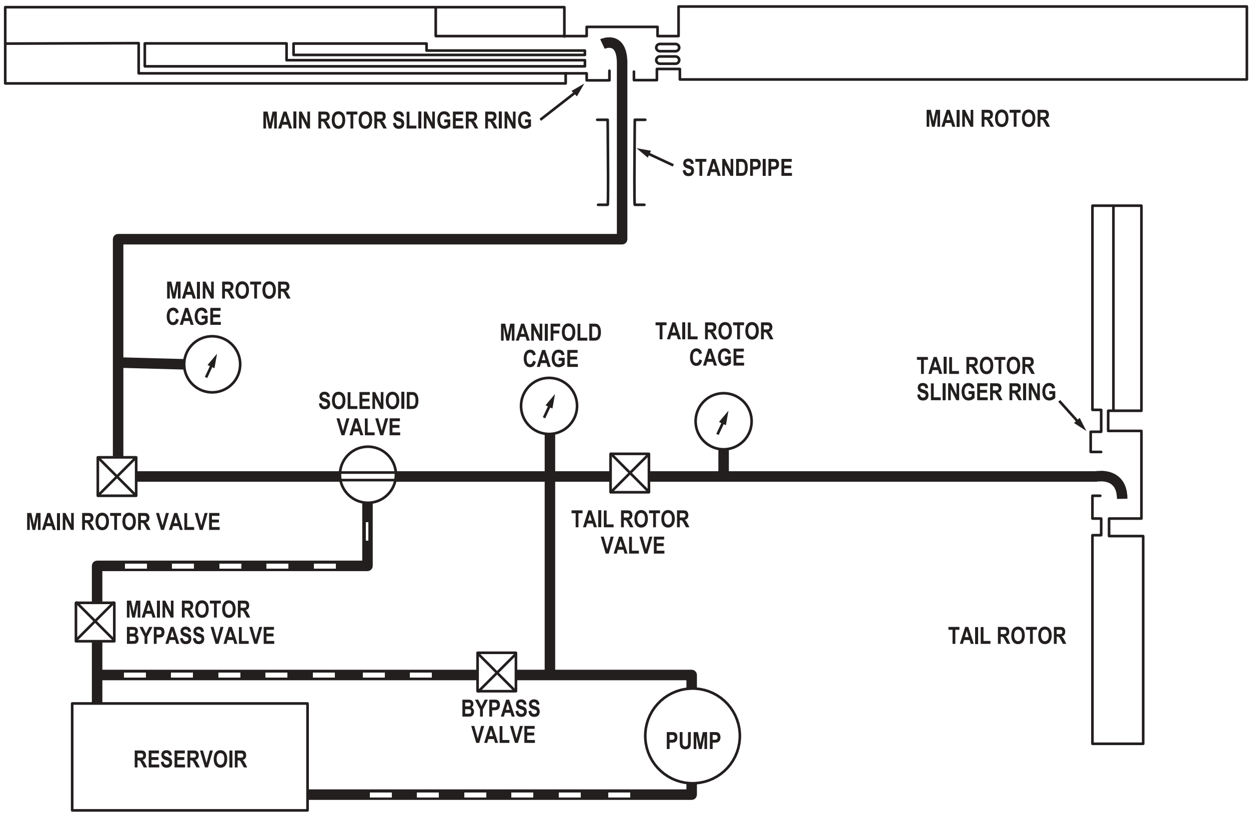


FIGURE III 3-10. SCHEMATIC OF HELICOPTER FLUID ICE PROTECTION SYSTEM
(Reference 3-12)

III.3.8 PENALTIES.

The principle penalty of the fluid protection system is the fluid storage requirement. The stored fluid weight may be significant when compared to other candidate ice protection systems. Added maintenance is required to check and resupply fluid to the system. Until a large number of airplanes use this system, the pilot cannot rely on the fluid being available at all airports and may be required to carry an extra supply.

III.3.9 ADVANTAGES AND LIMITATIONS.

III.3.9.1 Advantages of a Liquid Ice Protection System.

a. Reliable anti-icing protection is normally provided, thus there is no aerodynamic penalty due to ice accumulation.

b. The smooth flush panels impose no aerodynamic penalty due to the installation.

c. Runback icing is prevented due to the natural runback of the fluid.

d. Low power of typically 30 to 100 watts is required. No engine power is required for ground testing and emergency operation.

e. Hardware weight is comparable to or less than other systems (see tables in section III.6).

f. Components (except fluid and filters) are designed for the life of the aircraft, resulting in low maintenance requirements and cost.

g. Pilot skill and judgement required to operate the system are minimal.

h. The system can be used to prevent insect contamination on critical leading-edge surfaces.

III.3.9.2 Disadvantages.

a. The system has a finite period of protection, dependent on fluid supply.
b. Initial cost is higher than for a pneumatic system.
c. Fluid weight reduces useful aircraft load.
d. Fluid sometimes drips from the wings after use in flight.

III.3.10 CONCERNS.

Environmental considerations related to the use of a fluid ice protection system must be concerned with two aspects: the toxicity of the fluid to humans when they are in direct contact with the fluid or its vapors and the longer-term effects on the environment after fluid is shed into the atmosphere during flight. In this regard, only the characteristics of monoethylene glycol (MEG) are considered here.

While MEG can be toxic, it poses no danger to humans unless it is ingested in large quantities or a saturated mist or vapor is breathed for an extended period of time. Numerous studies (references 3-8, 3-9, and 3-10) have established that the threshold limit value for MEG vapor is approximately 125 mg/m^3. This is far in excess of vapor concentrations that can be induced due to natural evaporation of MEG in an airplane or airport environment. For droplets and mists of MEG, the threshold limit value is 10 mg/m^3. The single oral dose lethal to adult humans is estimated to he approximately 100 ml (reference 3-8). The principal effect of repeated small doses is on the kidneys due to the breakdown of MEG in the body producing kidney poisons. As with other fluids used in aircraft systems, care should be exercised to ensure that MEG is not accidentally swallowed.

If cabin pressurization is provided by compressor bleed air, a test of cabin air should be included while engine inlet anti-icing by FPD is taking place.

With respect to the environment, experiments (reference 3-11) have shown that MEG is biodegradable, with the rate being a function of temperature and the concentration of micro organisms present. MEG biodegrades completely in 3 days at a temperature of 60°F (20°C). At water temperatures of less than 46°F (8°C), biodegradation is completed in 7 to 14 days.

It should be noted that MEG is the principal constituent of the fluids used in great quantities to deice airplanes on the ground at major airports. The amount of fluid placed in the environment by a liquid ice protection system is quite small compared with the amount required to deice the same airplane on the ground. Therefore, it is claimed that the use of glycol-based fluids in aircraft liquid ice protection systems will have no adverse effects on humans or the environment.

Some concern has been expressed (reference 3-3) for the possible effects of FPD fluid on other parts of the aircraft: engine accessories, electrical insulation, or gold- or silver-surfaced electrical contacts. However, no evidence of deterioration has been documented in the several decades of use of FPD fluid for ground and flight ice protection.

III.3.11 REFERENCES.

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III.3.12 GLOSSARY.

Biodegradable—The ability of a substance when exposed to a natural outdoor environment to spontaneously break down chemically into compounds which have no harmful environmental effects.

Liquid water content (LWC)—The total mass of water contained in all the liquid cloud droplets within a unit volume of cloud. Units of LWC are usually grams of water per cubic meter of air (g/m^3).

Micron (µm)—One millionth of a meter.

Sintering—A metal hardening process such as heat tempering or adding an alloy to the base metal to produce a higher-density material.

Slinger ring—A torus-shaped tube with holes in the outer surface radius which serves as the distributor of anti-icing fluid for propeller and rotor blades. The ring is located at the hub of the rotor or propeller and rotates with the blades.